Design of an outfall diffuser and environmental analysis

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Abstract
This study analyzes the plume of effluent dilution in the water column, in relation to the currents variation and wind interference, for an outfall system in the region northeast of Brazil. Firstly, different configurations for the emissary were analyzed, resulting in an alternative approach that consists in the deployment of a diffuser system with 200 m and 50 ports at the end of each of the two existing lines of the emissary. This configuration provides values of dilution in the near field larger than the current condition. Studies of the far field showed that the effluent dilution ability depends on the currents behavior. The data analysis and the hydrodynamics modeling, showed that in the study region the wind is the determining factor for the currents pattern and consequently for the dilution capacity. Finally, it was found that, in summer, the best conditions for the plume dilution occur when the winds blow from N to ESE. In winter, the best conditions of dilution are observed when the winds come from SE to SW.

Keywords
Effluent dilution; outfall.

INTRODUCTION

This study began with a proposal for resizing an ocean disposal system (outfall) located on the northeast coast of Brazil. The results of hydrodynamic modeling, near-field and far field modeling, demonstrated that the winds action is the determining factor for the ocean circulation in the study region and, consequently, in the dilution of the effluent. This work will present: the proposed downsizing of the outfall, the currents variability and their correlation with the wind regime and, their interference in the behaviour of the plume in the water column and the effluent dilution capacity.

STUDY AREA AND ANALYSED DATA

The study area is located on the northeast coast of Brazil at 41 km north of Salvador.

Winds

The region presents high rainfall and climate variabilities along the year. This interannual variability is associated with variations in sea surface temperature (SST) patterns over the tropical oceans, which affect the position and intensity of the Intertropical Convergence Zone (ITCZ), thus modulating the rainfall in that region (Hastenrath, 1984, Moura &Shukla, 1981). The seasonal shift of the ITCZ contributes significantly to the seasonal variation of atmospheric circulation patterns in the region.

The summer months present dominance of Easterly winds, with strong zonal component, indicating the position of the ITCZ to the South. In winter months, the winds present a strong Southern component, associated with the displacement of the ITCZ to the North and the SE Trade winds over the region. Winds from S and SW are observed periodically throughout the year, with more energy than the trade winds; they are associated with frontal systems that bring rain during and after the event. Finally, Easterly waves, caused by the convergence of the Trade winds with the sea breeze, bring abundant rainfall and are more frequent in winter.

Wind data measured at the Meteorological Station of Arembepe (BA), at coordinates

12°46'18.00"S and 38º10'58.80"W (WGS-84), between July 2000 and March 2001, at sampling intervals of 30 minutes, were analyzed. The analysis showed a predominance of winds from E in summer while in winter there was a high percentage of winds from SE, SSE, S and SSW. For both periods the average intensity was 5 m/s; the strongest winds, higher than 10 m/s occured in winter months and came from S and SSW.

Currents

The current data were measured using acoustic profilers (ADCP) on two points (WGS-84):

- 12°51'15.20"S and 38º11'13,70"W, at approximately 35 m depth;
- 12°45'57.40"S and 38º07'4.10"W, at approximately 25 m depth.

The measurements were made during two periods: from July 09 to October 26, 2000 - representing winter months and from December 06, 2000 to March 22, 2001, representing summer months. The sampling intervals were always 30 minutes. The analysis of current data show that, in general, the predominant winter flow pattern is to the NNE and NE, and in summer, the main current is to SW.

These current direction patterns are determined by the influence of Trade winds, whose seasonal variability is associated with the displacement of the ITCZ. In winter, the ITCZ moves to North and the SE Trade winds drives the currents towards NE. In summer, the ITCZ moves to S and the E Trade winds forces the currents towards SW.

Elevation

The analyzed sea level elevation data are from the Tide Gauge Station Arembepe - BA (12°46'18.00"S and 38°10'30.60"W, WGS-84). These data cover the period from July 14 and October 24, 2000 (representing winter) and December 02, 2000 to March 21, 2001 (representing summer).The sampling interval is 30 minutes.

The harmonic tidal constants were obtained through harmonic tide analysis (Schuremann, 1941), applied to the data. The analysis indicated that the main components amplitudes for Summer were: M2 (68.21 cm), S2 (26.49 cm) and N2 (14.37 cm). For Winter the main components amplitudes were: M2 (68.37 cm), S2 (25.10 cm) and N2 (11.77 cm). All other components have amplitudes lower than 10 cm.

HYDRODYNAMIC MODELING

In order to simulate the hydrodynamic processes at the plume dispersion region, it was used the ORTHOHYDRO model, from WQMAP System, developed by the *ASA* (Applied Science Associates).

The meteorological forcing was introduced in the domain by specifying the surface wind field. At the numerical grid open boundaries, harmonic tidal constants, obtained from global ocean tide model of Schwiderski (included in WQMAP) were used.

The statistical analysis and the observation of current and elevation fields provided by the hydrodynamic modeling, showed that modeling could satisfactorily reproduce the main features of ocean dynamics in the region both in spatial and temporal scales.

NEAR FIELD MODELING

The modeling of the dilution factor in the near field was performed by the model CORMIX (Jirka et al., 1996).

Firstly, the near field dilution behavior, for the current outfall configuration, was analyzed. Wastewater characteristics:

- flow: 250 m^3/h at each line;
- temperature at the time of the launch: 26 to 29º C;

- effluent density: 1020.00 to 1040.00 kg/m^3 (the modeling considered 1030.00 kg/m^3, since it corresponds to the intermediate value).

The environment water density in summer is 1023.87 kg/m^3 at surface and 1024.69 kg/m^3 at bottom. In winter, it is 1024.06 kg/m^3 at surface and 1024.57 kg/m^3 at bottom.

The current velocity data allowed the calculation of the 10% percentiles. The 10% percentile value was used in the near field modeling, based on U.S. EPA (Environmental Protection Agency) requirements, for evaluation of effluent plumes (Brandsma, 2004), in order to provide the minimum initial dilution. The percentile values obtained were 0.060 m/s (winter) and 0.045 m/s (summer).

The statistical analysis indicated that the most frequent wind intensity was 4.7 m/s in winter, and 5.0 m/s in summer.

The simulations results for the current configuration (one port only for each line), indicated a near field of approximately 10 m. In winter, the dilution was of 6.8 times and, in summer, 7.4 times.

After these analyses, a comparative study of the effluent dilution plume behavior for different configurations of the outfall project was performed. The values of dilution in the near field and the cost of installation were the criteria for choosing the best configuration.

The chosen alternative consists of two lines of equal length, operating continuously with a flow of 250 m^3/h each. At the end of each line a diffuser system of 200 m lengh is proposed, with 25 risers and 50 ports per line (2 ports per riser), each port with an internal diameter of 0.05 m and 2 m height. The internal diameter of the pipe was kept (0.328 m) but risers with a diameter of 0.15 m are proposed. The results of these simulations showed, for the winter period, a dilution of 170 times in a near field of 8.4 meters. For the summer period, the dilution was 130 times in a near field of 6.4 meters.

FAR FIELD MODELING

In order to model the far field, CHEMMAP, developed by the ASA, was used to predict the trajectory and biogeochemical transformations of chemicals, including the floating, sinking and soluble substances. This model is able to use currents and winds fields, variable in space and time, and also consider the depth spatial variation.

The simulations to determine the effluent plume area of influence, in the far field, consider the meteorological and oceanographic forcing data variability. The scenarios considered different seasonal periods (summer, from December to February, and winter, from July to September), tidal flow regimes (ebb, flood and slack water) and tidal conditions (neap and spring). The initial conditions for each scenario are equivalent to the final conditions of the near field model, considering the settings for the chosen configuration. In order to represent the effluent, a $FeSO_4$ solution was considered at a concentration of 17,300 mg/L, being the concentration of dissolved iron of approximately 6 g/L.

The far field stochastic simulations indicate that for both periods the concentration (Fe dissolved in the water column) values vitiates between 17.34 and 3.47 mg/L, which represents a minimum and maximum dilution of 346 to 1,730 times respectively. In winter these maximum concentrations (17.34 mg/L) is observed within a radius of 260 m of the diffuser, while for the summer this radius is 310 m.

The probabilistic simulation results indicate that the probabilistic extensions of the area influence of the highest concentrations in winter is lower than in summer. It is understood that this result may be because of the currents winter are more intense than in summer. Figure 1 shows the influence area for probabilistic scenarios for summer and winter, considering the proposed final configuration.

ENVIRONMENTAL ANALYSIS AND CONCLUSIONS

Data analysis and results of hydrodynamic modeling showed that the wind is the determining factor for the oceanic circulation in the region. Aiming to determine the meteorological and oceanographic conditions unfavorable to the outfall plume dilution, an environmental assessment of the area and their influence on the behavior of the dilution plume is presented.

Iinitially were identified the events of current reversal, when the current ability to disperse the plume decreases. During these events the capacity for dilution is reduced and the plume concentration increases. For each event, the wind conditions were identified and characterized. Figures 2 and 3 present these analyses for summer and winter period, respectively. Figures show intensity and direction of current data on two locations and of local wind. Vertical lines locate the instants of reversal or decrease of currents vector and corresponding wind.

As example on summer (Figures 2), at January 14th there is a decrease of current vector on first data point and a current reversion on second data point, related with wind blowing toward 325º. Looking at other moments, the performed analysis showed that for the summer period the events of current reversal are associated with winds blowing toward directions equal or greater than 325°.

During the winter (Figures 3), at August 27th Eastward winds, blowing toward 280º result a decrease an reverse of the current vector. Looking at other moments, analyses for the winter period showed that events of current reversal are associated with winds blowing toward directions equal or less than 280°.

The typical number of events with these characteristics, for the summer and winter, was verified through analyzing 11 years (1997 to 2007) of wind data from NCEP. Table 1 presents the results, which indicate an average of 1.5 events per month in summer and an average of 3.1 events per month in winter.

Based on the results of far field simulations and the analysis of available data, it was found that the best conditions for dilution occurs:

- In summer (December-February) for situations with winds from N, NNE, NE, ENE, E and ESE. Winds of these directions occur in 68% of the time during the summer period.
- In winter (July-September) for situations with winds from the SE, SSE, S, SSW and SW. Winds of these directions occur in 62% of the time during the winter period.

And unfavourable conditions for dilution:

- In the summer occur in situations with winds from the SE, SSE, S, SSW, SW, which tend to reduce the current. Winds with these directions, in summer period, occurring in 24% of the time. These winds are usually associated with the passage of frontal systems across the region.
- In winter occur in situations with winds from the N, NNE, NE, ENE, E and ESE, which tend to reduce the current. Winds with these directions, in winter period, occurring in 34% of the time.

Therefore, in summer the presence of frontal systems, associated to winds blowing from South, tend to weak and in some cases to reverse, the currents direction. In winter, the winds that are able to reduce or to revert the currents are from the East, related to the Easterly waves (Trade winds interaction with the sea breeze).

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Table 1 Number of occurrences associated with a possible currents desintensification or reversal in summer (January to March) and winter (July-September).

Year	Summer		Winter	
	Number of occurrences	Number of occurrences per month	Number of occurrences	Number of occurrences per month
1997	4.0	1.3	12.0	4.0
1998	5.0	1.7	8.0	2.7
1999	6.0	2.0	3.0	1.0
2000	5.0	1.7	12.0	4.0
2001	10	3.3	9.0	3.0
2002	4.0	1.3	12.0	4.0
2003	4.0	1.3	6.0	2.0
2004	4.0	1.3	6.0	2.0
2005	2.0	0.7	7.0	2.3
2006	3.0	1.0	15.0	5.0
2007	3.0	1.0	13.0	4.3
Average values	4.5	1.5	9.4	3.1
Standard deviation	2.1	0.7	3.7	1.2

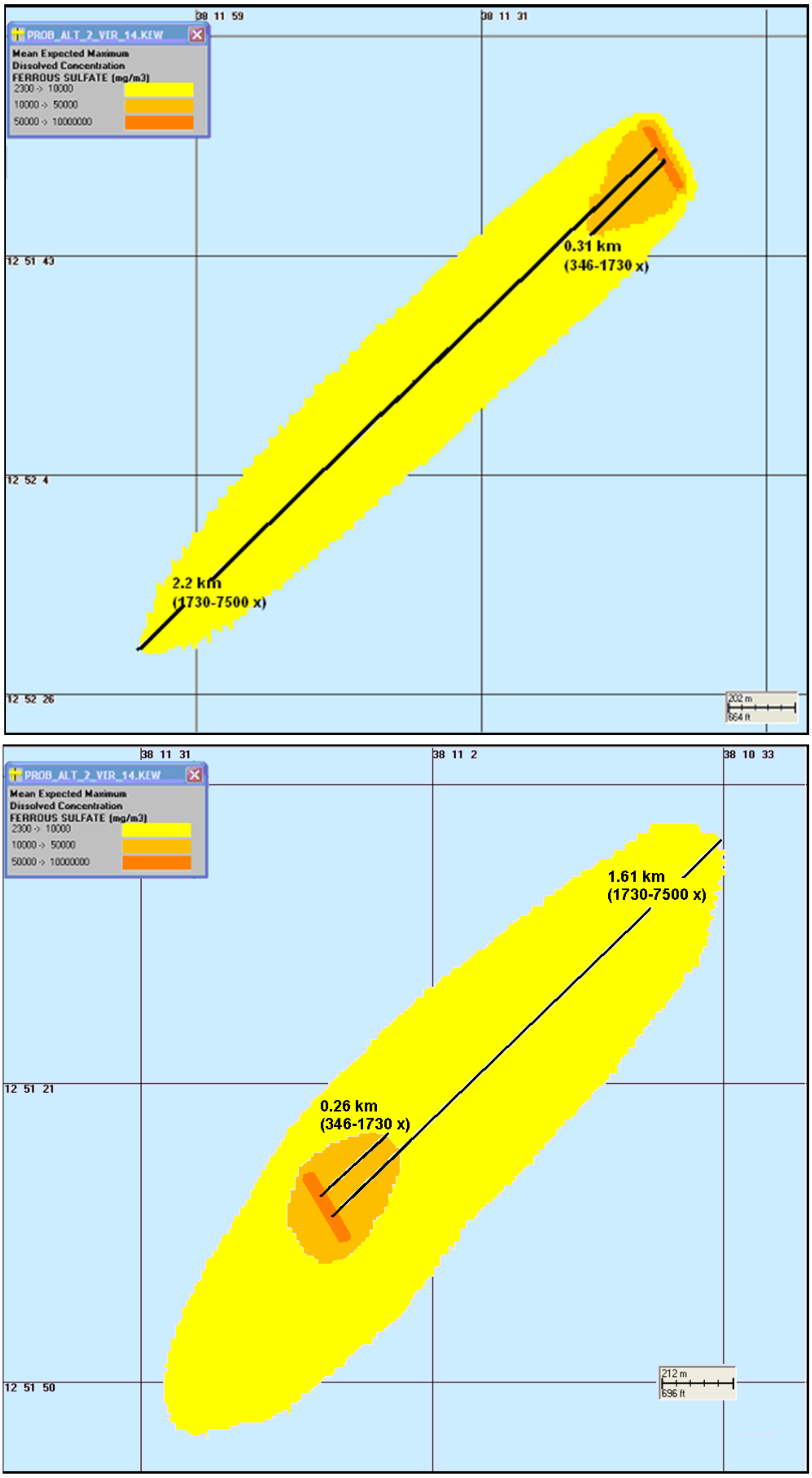

Figure 1. Detail of mean maximum concentrations (mg/m^3) of $FeSO_4$ expected, for summer (above) and winter (below), 24 hours after discharge for proposed final configuration.

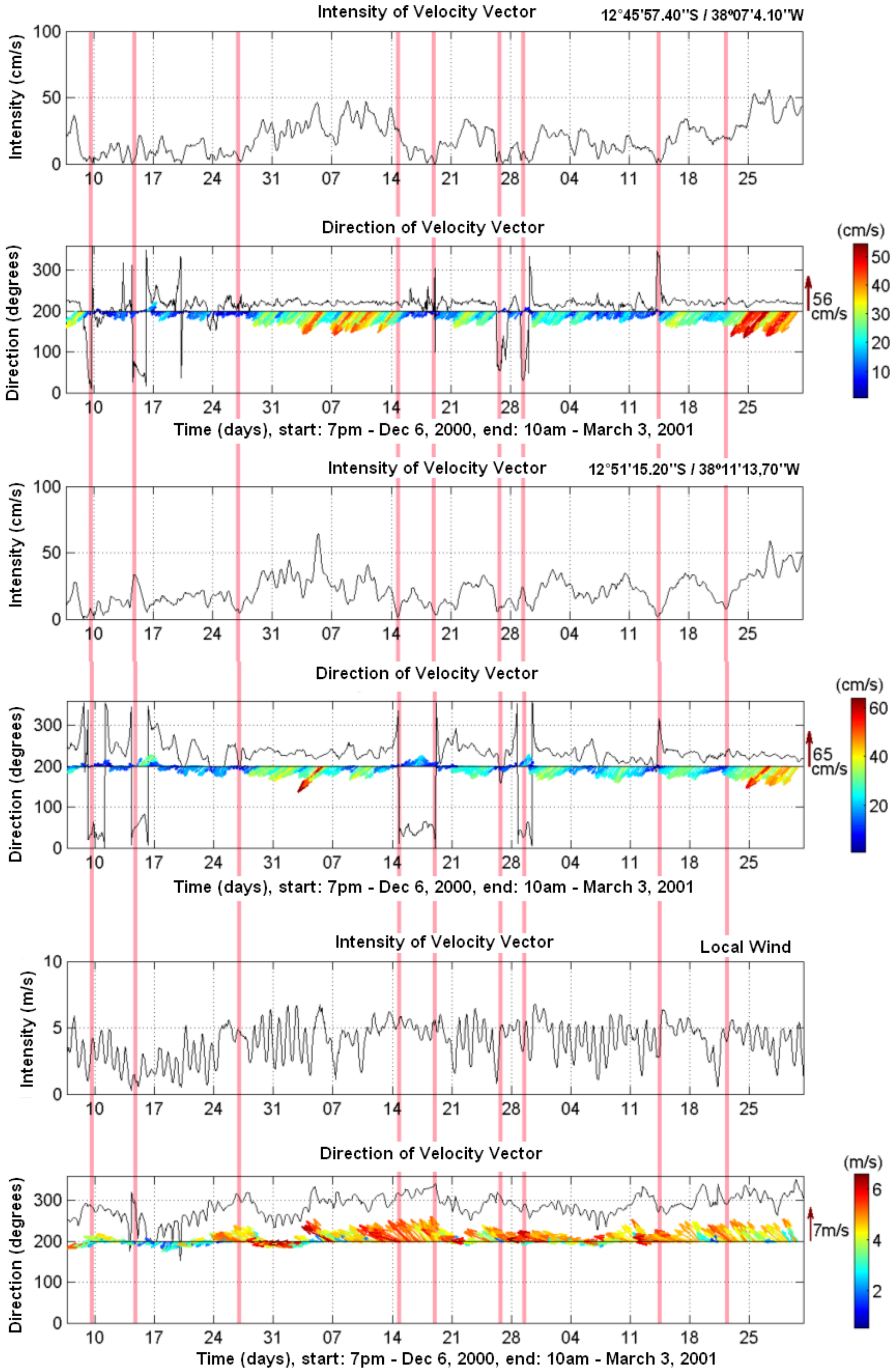

Figure 2 Current data (5 m depth) in two different points and local wind data, summer period.

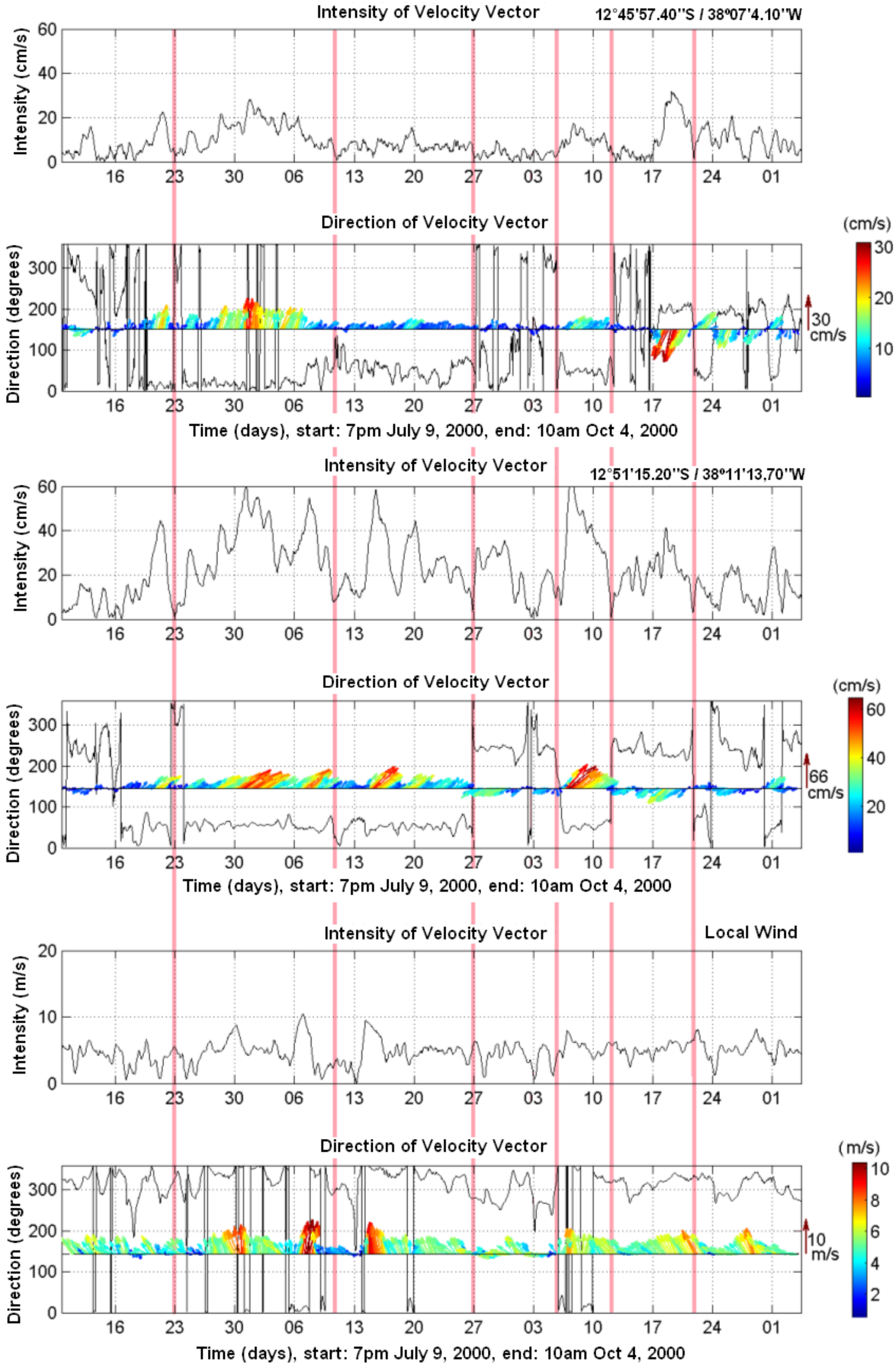

Figure 3 Current data (5 m depth) in two different points and local wind data, winter period.